The Two Sides of a Double-Skin Facade: Built Intelligent Skin or Brand Image Scam?

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ABSTRACT: Double-Skin Facade (DSF) buildings regularly appear in popular architectural journals and claims are made that the buildings are either ‘sustainable’, ‘green’, ‘eco-friendly’ or ‘intelligent’. This results in myths about the performance of buildings that are perpetuated by designers eager to maintain a brand image. A literature review of research on the performance of DSFs reveals that the vast majority of the analysis is carried out by simulation methods and that there is a lack of empirical evidence obtained from monitored buildings.

This paper will present some early findings from buildings with DSFs that are currently being monitored in Auckland, New Zealand, to assess the contribution of a DSF to reducing the building’s heating and cooling load. It will also analyse the common simulation models to examine whether the models are a reasonable representation of reality. Initial evidence indicates that DSFs in sub-tropical climates offer less energy savings than predicted and could even contribute to increasing cooling loads.

It is the hypothesis of this paper that a DSF has become a way in which an excessively glazed building in a warm climate can maintain its transparent architectural image while still claiming to be ‘green’ but with little evidence of any energy savings.

Conference theme: Sustainability issues
Keywords: double-skin facade, cooling load, architectural image

1. INTRODUCTION

During the past few years, the level of interest in double skin facades has grown rapidly due to the benefits claimed in terms of energy conservation and noise insulation that contribute towards ‘green building’ credits. The popularity of this kind of building has increased significantly among architects in New Zealand with the advent of the Green Star NZ rating system. The most common form of DSF has been an additional glazed layer set in front of a sealed air-conditioned building in particular where there are large areas of glass exposed to the sun at peak times of solar gain.

Some researchers claim that DSFs decrease buildings’ cooling loads (Chan, Chow, Fong, & Lin, 2009; Hien, Liping, Chandra, Pandey, & Xiaolin, 2004; Saelens, Roels, & Hens, 2007; Torres et al., 2007). Some studies however show DSFs often result in higher consumption of energy for the building’s cooling because of a poor performance of the DSF (Gratia & De Herde, 2007; Stribling & Stigge, 2003). It can also lead to catastrophic results such as the injection of the DSF hot air to the internal spaces during summer when the building should be cooled (Gratia & De Herde, 2003a, 2003b). There are also cases where summer overheating problems have to be compensated by excessive and unanticipated use of air-conditioning systems (Streicher et al., 2007).

Regarding energy saving, DSFs have great potential to improve the building envelope in continental and temperate climates (Stribling & Stigge, 2003). Given that Auckland climate is semi sub-tropical, the suitability of these kinds of components requires further research.

In New Zealand, many of the buildings which are claimed to be green have a DSF in their concept; such as the NZI Centre, the Deloitte building, the Department of Conservation Offices, the Meridian Head Office, and the Christchurch City Council’s Civic building. They have been accredited as ‘green’ buildings using the voluntary New Zealand Green Building Council’s rating tools (Byrd, 2010).

So far, however, there has been no known investigation into field measurements of energy saving related to the DSFs. Research on the performance of double skin facades is mostly done by simulation (Gratia & De Herde, 2003a; Hien et al., 2004; Torres et al.) or mock up model measurements (Chan et al., 2009; Fallahi, Haghighat, & Elsadi, 2010; Gavan, Woloszyn, Kuznik, & Roux, 2009; Kim & Park, 2011; von Grabe, 2002). Limited work has been done based on the actual field measurements. In this work, validity of the test room results is not studied.

Most simulation results have deviated from real measurements in the finished building (Streicher et al., 2007). This issue will be further discussed in Section 2. The influence of DSFs on building envelope temperature is investigated by monitoring two office buildings in Auckland. The preliminary results are described in Section 3.

This study addresses the gap in research carried on DSFs in two main ways. Firstly, different energy simulation tools are investigated in regard to their application and advantages/disadvantages. The reasons why simulation models are not representative of real buildings is discussed. Secondly, after introducing the case studies, graphs of temperature inside and outside the cavities are analyzed to study the effect of DSF on the temperature of the building.

2. SIMULATION

In this study, we first conducted a comprehensive literature review of energy performance simulation programs for DSFs. An excellent and recent literature database of all issues related to DSFs is found in the BESTFACADE report (Streicher, 2005). It aims to give an overview of the state of the art concerning the published and relevant literature in the field of DSFs. It contains all references of articles, books, proceedings, diploma thesis and PhD thesis regarding double skin façades until 2005. The relevant literature in this report together with the literature after 2005 identified 50 studies which have modeled the DSFs in order to study their performance. Only two of the 50 papers reviewed have validated the simulation models with real building performance. Figure 1 shows the modeling methods used in these studies.

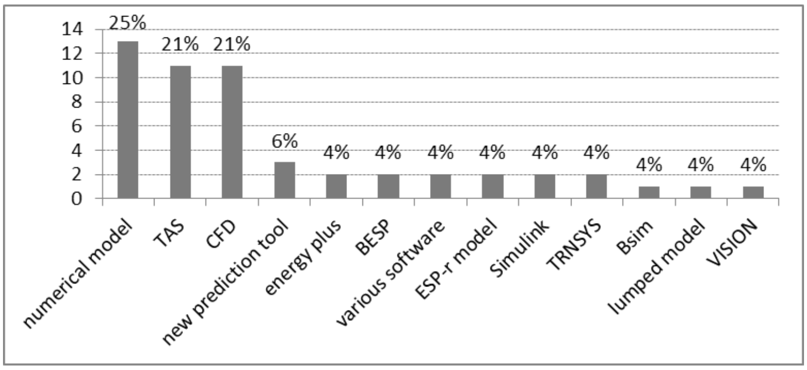

Figure 1: different modelling methods Source Wolfgang Streicher, 2005

The chart shows that most of the studies use numerical model. The numerical models are developed to simulate the different behaviors of the buildings (Zanghirella, Perino, & Serra, 2011). For example, it can be composed of airflow and thermal models (Fallahi et al., 2010) which is based on matrix algebra. The most popular computer programs among all energy simulation software programs are TAS and CFD. Some researchers have tried to invent new prediction tools (von Grabe, 2002; Yılmaz & Çetintaş, 2005). There are some other programs which are used in studies shown on Figure 1.

Some studies claim that simulation of double skin facades with software is a good representative of the real performance of the building (Chan et al., 2009; Fallahi et al., 2010; Pasut & De Carli, 2011). They are, however, based on validation of the simulation results by test room measurements and not the monitoring of a real building. Some others claim that building simulations can be far from reality (Kim & Park, 2011; von Grabe, 2002). Some researchers have even gone further and claim that “[a]n accurate energy model for an annual performance assessment of a DSF does not exist.” (Pappas & Zhai, 2008)

A review of literature, which has investigated the simulation programs, shows the various reasons for the inaccuracy of simulation methods are:

2.1 The simulation results are not adequately validated. It is difficult to trust the results of computer simulations, as the existing models are rarely verified with real building data (Pappas & Zhai, 2008). Most of the validations are from test facilities (Chan et al., 2009; Kalyanova et al., 2009; H. Manz & Frank, 2005). As the test room sizes are much smaller than real buildings, their results cannot generalize to performance of real buildings.

2.2 The simulation results should be calibrated with an experimental study (Champagne, 2002; Heinrich Manz, 2002). Studying various publications shows that the risk of generating poor results without calibrating the simulation model with measured data is high. On the other hand, being confident about the simulation results requires further work including both measurements and more detailed and robust simulation programs (Jensen, Kalyanova, & Heiselberg, 2008). Even after calibration, their results cannot be generalized to other configurations of double-skin facades, and are insufficient for the technical design of a double skin.

2.3 Some factors are difficult to be modeled. Some studied examples demonstrate the sensitivity of the prediction and difficulty of modeling (von Grabe, 2002). The most problematic factor in the majority of studies is flow condition which, by their nature, is unpredictable. Also, it is difficult to find a program which has the capability of considering all factors together.

2.4 Each software is suitable for a certain purpose. The choice of the software depends on the level of design which requires a particular type of analysis (Hensen, 2004). As yet, no single software tool can accommodate all the complex processes occurred in the double-skin façade (Zhou & Chen, 2009). Modeling the building with reliable results is not possible with simulating the building through single software (Hensen, 2004; H. Manz & Frank, 2005). For a good DSF simulation, the air flow, the temperature at different heights, and daylight should be modeled all together. Therefore, for a complete simulation of a building, one should be able to handle different software (Zhou & Chen, 2009).

2.5 Some of the programs are complicated and require powerful computers. (Champagne, 2002) stated that the modeler should be highly expert to be able to simulate the building with the suitable software; otherwise, wrong data can result from these simulations. Modeling fluid flow and heat transfer by computer simulation is very complicated. In order to succeed with calculations, not only practical experience of the used simulation models is required, but scientific knowledge of thermodynamics, fluid dynamics, building physics, and general shrewdness and experience of building services engineering is vital (Streicher et al., 2007).

In conclusion, for an accurate simulation, we need: domain knowledge; ability to select the appropriate level of extent, complexity and time and space resolution levels; calibration and validation; and a correct performance assessment methodology. Considering all of these factors together is very difficult. Therefore, often the simulation results are far from the reality.

3. CASE STUDIES

In this section, after introducing the case studies, their cavities' performance will be analyzed through the measured data. The studied buildings are two office buildings situated in Auckland: : For purposes of anonymity they are called Building A and Building B. Both buildings have been in operation for about 2 years and the various commissioning issues have been resolved.

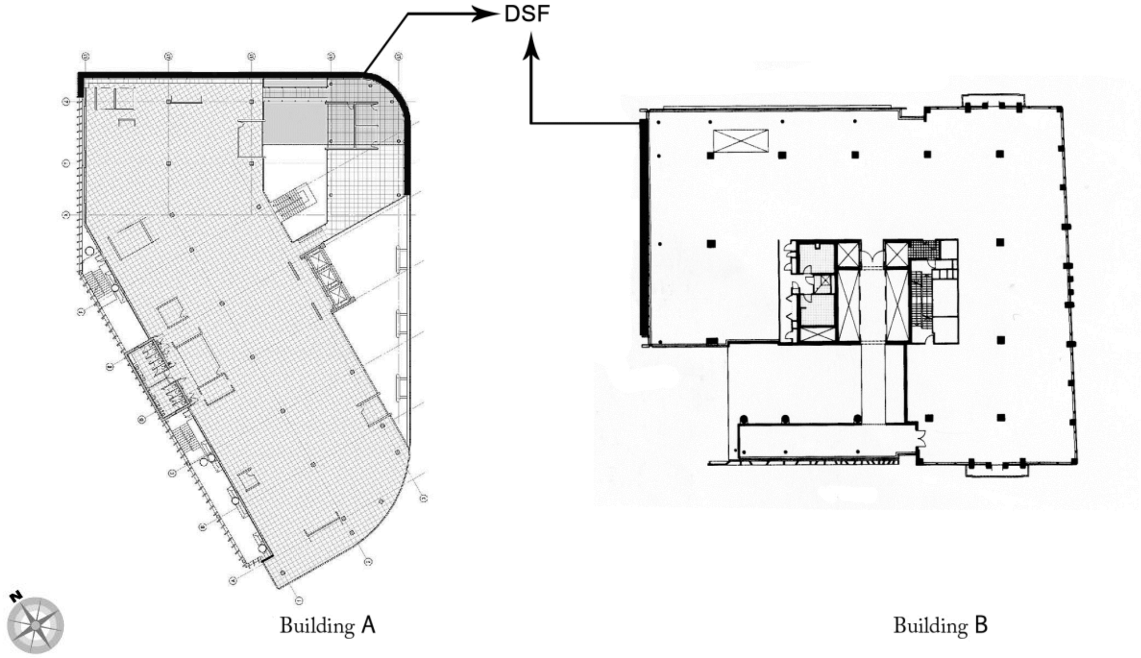

Figure 2: The Case Studies Plans and their DSF locations

3.1. Building A

The first case study is a five storey commercial office building which is principally oriented towards north-east, as indicated on the plan. The DSF, with about 60cm cavity width, is from the second floor to the top floor on the north side of the building. The whole building covers 9250 m2 and it houses 700 staff. It has a number of sustainable features including:

- the innovative use of a large scale underfloor air conditioning system,
- rainwater collection from the roof that supplies a water for the toilets
- a diagrid façade with a mix of high performance double glazing and double skin glass façades to the North
- a green roof / roof terrace

It is claimed that the building HVAC system is one of the most complicated ones due to use of under-floor air-conditioning and automated venetian blinds within the cavity of the DSF. The rooftop incorporates the HVAC plant room. Three large, circular skylights above the atrium enable deeper penetration of natural light into the floor plates of the working areas, and are also used to create a naturally displaced return air path: convection causes air to circulate naturally within the space.

The inner skin of the façade is a double glazed from the floor to the ceiling. The façade is completely sealed and there is no opening on either the inner or outer façade. The outer skin of the façade is single glazed clear and the air inlet and outlet are located at the bottom and top of the cavity respectively. The automatic venetian blinds are installed inside the cavity and its cleaning is possible through grid floors.

3.2. Building B

The second case study is a tall (25 storey) office building with the DSF facing north-west. There are two separate DSFs; one of them is from 2nd to 6th floor and the other one is from 8th to 21th floor with 600mm width at the west side of the building. According to the media ("Warren and mahoney website," 2012; "Woods bagot official website," 2012), this is one of the most environmentally sustainable commercial office buildings in the country and pioneered the development of the New Zealand Green Building Council rating system.

This building uses high efficiency variable speed drive chiller, pumps and fans that reduce electrical demand during non-peak periods. The plant room of this building is situated at the upper three levels and at level 7.

4. MEASURED DATA

4.1. Climatic data

Data of solar radiation intensities was taken from the National Institute of Water and Atmosphere (NIWA) station within 2kms of the sites. For this preliminary study, measurements, both solar radiation, external temperatures and cavity temperatures, were taken over a two month period in the winter.

4.2. Measuring equipment

In order to measure cavity temperature, DT-171 data loggers and DS1922L ibuttons were installed. Readings were taken at 20 minute intervals. The data loggers were located as indicated in Figure 4 and were kept out of any direct sunlight. Internal loggers were located in both the air intake registers and in the rooms at a height of 1.8m and set in from the facades by about 3 metres.

Figure 3: Building A Cavity

Figure 5: Building B Cavity

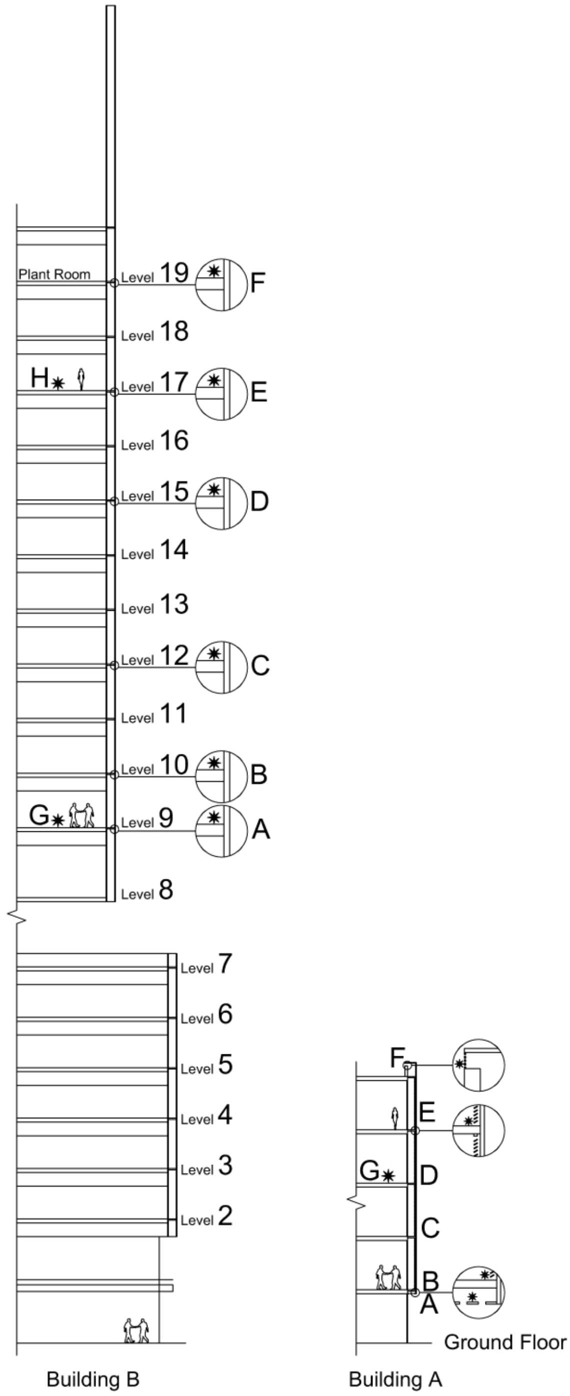

Figure 4: Case studies sections and measurement devices locations

4.3 Energy use

As prominent 'green' buildings, neither of the building managers wished the energy use of the building to become public. However, both buildings are conditioned 24 hours per day, 7 days per week and they remain in cooling mode throughout the year except for a short period in the winter when the chillers are not required. It appears that, in the short periods of time when heating is required, this is satisfied by internal heat gains from equipment and lighting.

4.4 Results

Figure 6 indicates both cavity temperature and solar radiation intensities on both a typically sunny and typically cloudy day in building A. The increase in cavity temperatures is almost entirely due to solar heat gains with external temperatures having little effect.

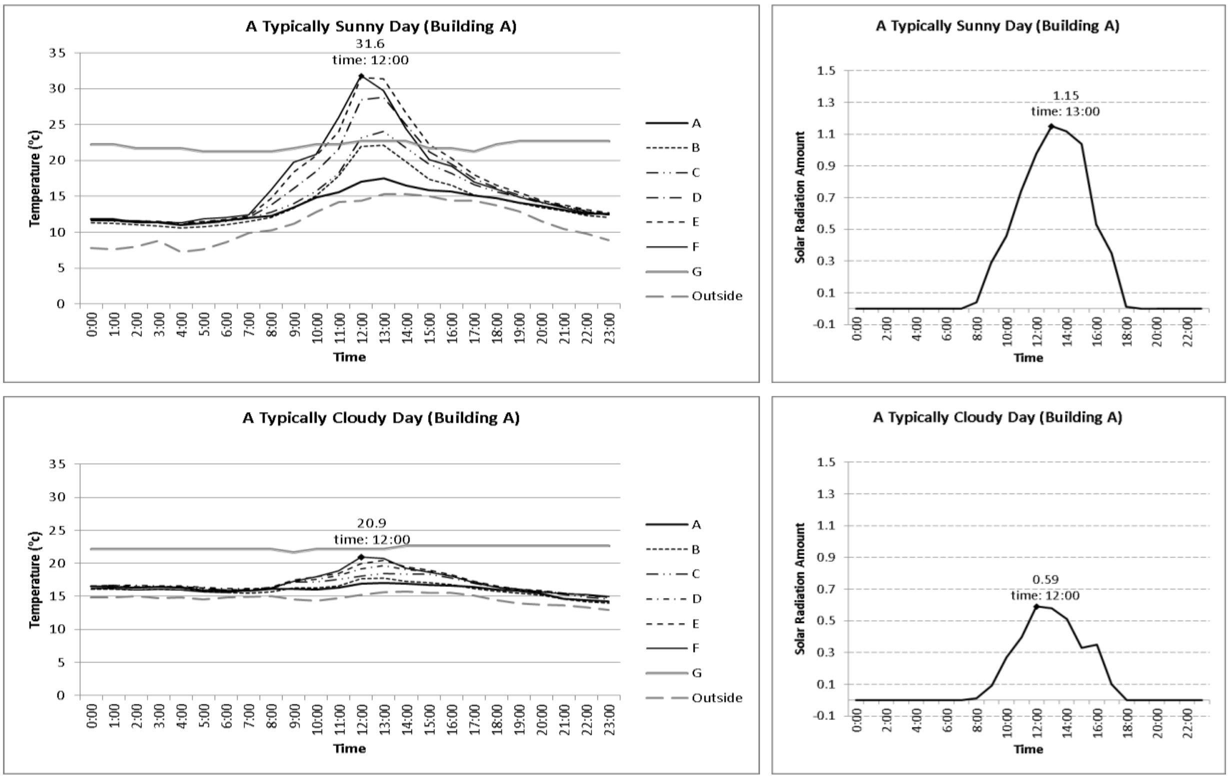

Figure 6: Cavity temperature and solar radiation intensities on typically sunny and cloudy days in building A

Figure 7 indicates temperatures within the building B cavity on a typical day. As expected, the DSF that was facing north-west reached its peak temperatures about four hours after the DSF facing north-east. The peak temperatures in Building B, the taller DSF, were higher than the shorter building (Building A). On a typically sunny day, cavity temperatures exceeded room temperatures for about 4.5 hours per day in Building A, while only for about 2.5 hours per day in Building B.

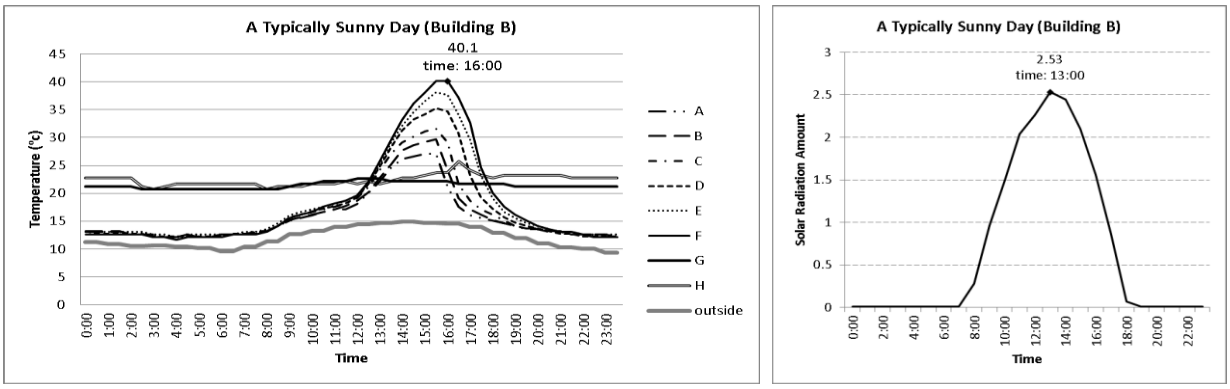

Figure 7: Cavity temperature and solar radiation intensities on a typically sunny day in building B

However, of greater interest is the gradient in temperatures up the DSF's of the two cases. This is indicated in Figure 8. The temperature increase per floor height in Building A was 3.8°C per floor compared with 1.1°C per floor in Building B. The temperature gradients were linear in both cases.

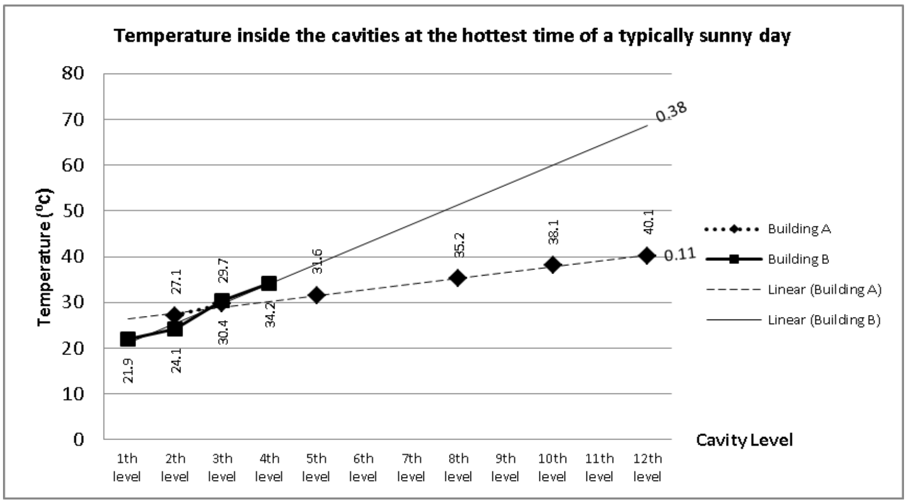

Figure 8: The gradient in temperatures up the DSF's of the two cases

At this early stage, we consider that this is due to a combination of effects:

1) The taller building has a greater stack effect and draws air in at a higher speed.
2) The openings to the base of the DSF are considerably smaller for Building A (0.14 ^{2}/liner m) than Building B (0.6 m^2/linear m). (Figure 9)
3) The extensive blinds within the cavity of Building A may have had some effect on the flow of air and slowed it down due to friction and eddies.

Building A

Building B

Figure 9: Cavity inlets

4.5 Discussion

Prior to the monitoring of these buildings there was no public data on the extent to which commercial buildings in New Zealand were in cooling mode throughout the year. While the exact energy consumption figures are confidential, the results indicate that highly glazed buildings in a semi-sub tropical climate are in cooling mode for most of the year and that internal heat gains are adequate to heat the buildings during the few weeks of a net heating demand.

The DSFs were included in the design of the buildings to assist in both winter heating and summer cooling. The results indicate that they offer little or no benefit to winter heating. The air temperature within the cavities of the DSF is considerably higher than either external or internal temperatures and, therefore, contributes to the cooling load of the building.

Had the DSFs not been installed, there may have been higher solar intensities (had solar control devises not been installed) on the glazed envelope of the building, but significantly lower temperatures. In the case of Building A, blinds within the cavity effectively eliminate direct solar radiation and so increased temperatures in the DSF produce an unwanted additional cooling load. A similar, but lesser, effect occurs in Building B where the internal blinds are continually closed.

As solar intensities and external temperatures increase in the summer, we anticipate that the cavity temperature will also increase and further contribute to the cooling load. The monitoring will continue over a summer period and the results subsequently published.

Based on the data and at this preliminary stage, we conclude that DSFs in a semi-subtropical climate that are applied to sealed, air-conditioned buildings, such as those analysed in this research, have a detrimental impact on the energy performance of the buildings since they only contribute to an increased cooling load.

More effective means of reducing solar heat gains would be to reduce the proportion of glazing and to add external shading. This would have had significant impacts on the ‘all-glass’ image of the building.

5. CONCLUSIONS

Of the considerable literature available on DSFs on commercial buildings, the vast majority have predicted the energy performance by modelling. The accuracy of the modelling has been questioned by other researchers and the results of modelling have differed with some claiming that DSFs are beneficial and others that they are detrimental.

This study has taken actual measurements within two office buildings and their DSFs over a winter period. Since there is a net cooling demand in the buildings over almost the entire year, the temperatures within the DSFs contribute to the cooling load.

The results of this research support the supposition that DSFs are more a means of maintaining an ‘all-glass’ architectural aesthetic than a considered response to energy efficiency.

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